Increases in Costs and Returns Due to Intensifying Range Forage Production Surveys: An Information Economic Analysis

Giles T. Rafsnider, Melvin D. Skold and Richard S. Driscoll

The U.S. Congress and courts have directed federal natural resource agencies to use better information for management decisions than they have used in the past. It is also important for these agencies to improve the efficiency of resource use where possible. This information economics study estimates increased costs and revenues which can be directly imputed to improving the accuracy of range forage production surveys. It suggests that a high level of survey accuracy may often be justifiable.

Legislation specifies that federal forest and range lands shall be managed to provide goods and services at levels which are sustainable in perpetuity. To assure these flows the Bureau of Land Management (BLM), the Soil Conservation Service (SCS), and the U.S. Forest Service (USFS) are required to survey or periodically assess the biological and economic potential of the nation's public and private natural resources.[1] This legislation reflects the congressional mandates for more accurate information than that previously used in making management decisions.

These laws and regulations have had a further impact on the range-management environment and activities which had already begun changing markedly following the National Environmental Policy Act (P.L. 91-190). Proposed management plans have been challenged on one or more of several legal grounds. As a result of Natural Resource Defense Council vs. Morton (388 F.Supp. 829, affirmed 527 F.2d 1386) the BLM, U.S. Department of the Interior, must prepare detailed range production surveys, management plans, and supporting environmental impact statements for each grazing allotment. The USFS, U.S. Department of Agriculture, was similarly affected by California vs. Berglund (483 F.Supp. 465), which arose from its RARE II (Roadless Area Review Evaluation)

Giles T. Rafsnider is Temporary Associate Professor in Department of Economics, Colorado State University. Melvin D. Skold is Professor in Department of Economics, Colorado State University. Richard S. Driscoll is Program Manager at the Rocky Mountain Forest and Range Experiment Station, USFS, Ft. Collins, Colorado.

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[1] Federal Land Policy and Management Act (P.L. 94-579), Soil and Water Resources Conservation Act, (P.L. 95-192), and Forest and Rangeland Renewable Resources Planning Act (P.L. 93-378) as amended by the National Forest Management Act (P.L. 94-588).

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study and its recommended wilderness area designations.

A major factor leading to the courts' findings was based on the accuracy of information used in the decision process. The BLM and the USFS have long conducted extensive sample surveys of the rangelands they manage. The agencies must now be more concerned with both appropriate sampling intensity and the ways these samples are distributed through time and across geographic space.

This paper addresses the accuracy issue, particularly the costs and benefits of surveys used to estimate range forage production. Public land management agencies operate under laws and regulations which require limiting grazing intensities to levels that do not damage grazing lands. Consequently, federal land managers can be assumed to be conservative in the stocking levels they allow on those lands. If they err it will be on the safe side by underutilizing rangelands. As a consequence, less forage may be sold than is available for use. It is also assumed that ranchers will buy all the federal grazing offered for sale. Increased accuracy in forage production estimates would enable public land managers to reduce their uncertainty discounts and may increase the amount of public land grazing sold. These assumptions make it possible to develop cost curves for evaluating increased survey accuracy and revenue curves reflecting increased forage sales. Combining these two makes the determination of an optimum survey accuracy level possible.

Value of Information

The economic value of information generated by private and public agencies derives from its use in decision making. The cost of increased accuracy must be weighed against its value. Costs usually reflect data gathering while value is measured by increased revenues or decreased expenses. Further, forecast errors and the way information is perceived and acted on by the potential beneficiaries are also important. The magnitudes of benefits accruing to individuals or groups depend upon the expertise with which information is generated and used (Bradford and Kelejian).

Private groups usually sell information for profit or use it to gain a competitive advantage. It has been shown that private advance information can add significantly to private profits (Hirshleifer). The value of additional information is high if current information is sparse and new knowledge can be put into practice. But experimental costs should be low relative to production profitability (Anderson and Dillon). The composition of new information is also important. It was found that for corn production in a local area, the value of additional information and the value of increased precision of estimates were about equal (Havlicek and Seagraves). A further study revealed that spatial variation is a significant contributor to information collection costs and benefit levels for producers in aggregate (Perrin).

Government agencies collect and place information in the public domain.[2] The magnitude of social benefits from these activities depends upon whether information is used to refine production or inventory decisions (Hayami and Peterson). Social costs are not symmetrical for over or under forecasts of the same magnitude. Further, the social cost of an overforecast has been found to be relatively small (Bullock; Hayami and Peterson). This latter finding is particularly relevant to the present analysis. Although overstocking may impair productivity and require eventual expenditures for renovation, understocking might be the more serious issue.[3] If production is underestimated for

[2] Except for classified data and analyses for national defense purposes, it is available to all users.

[3] Since sampling schemes are symmetric with respect to confidence intervals and confidence levels, it is

a series of years, the range will subsequently be understocked. Because stocking rates cannot be adjusted rapidly, given the institutional framework in which rates are set, federal agencies may lose grazing receipts. Ranchers may have to reduce herd sizes or incur extra expenses to purchase alternative forage supplies.

Range Production Measurement

Historically, surveys have been used to determine baseline range forage production on grazing lands. After the survey, condition and trend measurements are taken at specific time intervals to monitor variation from base production levels. Accounting for annual variation is important when managers set yearly stocking levels. A vegetation survey is much like the U.S. population census taken every ten years. Monitoring it is similar to keeping track of births, deaths, and net migration so population in the years between censuses can be estimated. While reliable models of human population growth have been developed by demographers, plant ecologists have faced greater difficulties. The latter must deal with great variability in major factors of production such as temperature and precipitation.

Statistical estimates of plant production have low explanatory power. Further, data sets used to determine annual range forage production have been relatively small and insufficient for estimating and driving projection models. Refining some parameters can improve growth predictions. A 10 percent error in estimating forage availability leads to understocking by about 8 percent: each 1 percent increase in prediction accuracy increases the allowable grazing by 0.8 percent (Hunter). However, prediction of plant growth, with 95 percent reliability, requires at least 10 years of weather conditions and 4 plots per soil type. Given the usual variability in soils, large samples are needed for large geographic areas (Redetzke and Van Dyne). The 80 percent confidence level is suggested as a reasonable compromise for most range production studies (Mueggler). Even so, more than 500 randomly distributed plots were needed to estimate production levels for some individual species. However, the number of plots needed can be reduced by sampling plant associations. Statistically, valid estimates of aggregate forage production require less data than does the same estimate for individual classes of plants.

This study involves application of a technique to determine the sample size required to estimate annual native range forage production over a decade. The decade was chosen so analytical results would conform with legislation that requires stable, nonexploitive, annual grazing levels. Some annual variation is allowed, but the law requires that the average over ten years must be on target.

Data for the analysis was contained in a long-term SCS study in northern Utah and eastern Idaho (Passey *et al.*). Weight estimates for sagebrush-wheatgrass range forage production were collected annually at 17 sites between 1957 and 1970. Because sites were added and dropped during the study, complete data were found only for 1960 through 1969. The sites were on private land and covered a study area of 44,048 hectares.[4] Production was reported for grasses, forbs, and browse both individually and also summed for total range output. Production levels analyzed are averages for 20 plots randomly scattered about a point at each of 17 sites.[5]

The SCS data set was treated as a pre-

the happy circumstance that intensification of sampling to prevent understocking will at the same time provide data that can be used to help avoid overstocking.

[4] Based on range survey intensity standards in force when the SCS research was underway.

[5] The plots were circular and covered an area of .89 square meters (9.6 square feet).

sample used to determine sample sizes necessary to make statistically valid estimates of grass, forb, browse, and aggregate forage production at 70 through 95 percent significance levels and at confidence intervals of −10, −20, and −30 kilograms per hectare.[6] The significance levels and confidence intervals represent the degree of certainty and the tightness attached to estimates of production, respectively. Sample sizes estimated for a decade from pooled data shown in Table 1 are the basis for calculations in this paper.

Following legislative mandates, annual stocking levels can not exceed biological carrying capacity averaged over ten years. Because managing agencies have both annual and decadal performance requirements, it is necessary to determine both total and annual sample sizes and their distribution throughout the grazing area. How samples should be geographically drawn is not considered in this analysis because data about spatial variability due to soils and other factors are not available. Further, since systematic weather patterns can not be identified, it is assumed that annual weather is a random variable. In the absence of a priori statistical information to the contrary, the size of samples drawn annually should be equal in order to capture as much between-year variability as possible. To determine annual sample size, we divided the figures in Table 1 by ten.

Benefits Resulting from Increased Forage Survey Accuracy

This analysis considers the net value gained by increasing the statistical accuracy of range forage production surveys used to determine stocking rates. Given the conservative nature of the stocking level dictated by federal legislation, the amount of public land grazing available to users is rationed by the public management agencies. Stocking rates are set at levels below the optimum suggested by deterministic (nonstochastic) analyses. Increased survey accuracy may lead to increased stocking rates, which in turn reduce the positive opportunity costs caused by underutilization.[7] Table 1 indicates that estimation of grass production requires the most data. Cost calculations in Table 2 are based on sample sizes necessary for determining grass production.[8] Finally, it was assumed that average per acre productivity calculated by pooling all 17 sites and 10 years of data represents average annual long-run output. This average is used to determine the total forage production which is identified at each of the three confidence intervals.

Average annual long-run forage output represents total potential range production. However, not all of this forage can be grazed without damaging the range. Some material must remain to guarantee

[6] Sample size is determined by

$$N = \left(\frac{Z_{\alpha/2}}{c}\right)^2 \sigma^2$$

where N is sample size, σ^2 is the sample variance, c is the desired accuracy of the sample mean, $Z_{\alpha 2}$ is the abscissa of the normal curve that cuts off an area $\alpha/2$ at the upper tail (Boo and Epstein).

[7] Laws and regulations specify that the maximum grazing rate on public lands may not exceed a level the forage resource can sustain without damaging long-term biological productivity. This sets an upper bound on AUM's which may be sold. Our analysis deals with down-side losses of grazing fees caused by underestimating carrying capacity by $\hat{\mu} - 10$, $\hat{\mu} - 20$, and $\hat{\mu} - 30$ kg/ha. It would be both difficult and inappropriate to extend the analysis to up-side losses (i.e., $\hat{\mu} + 10$, $\hat{\mu} + 20$, and $\hat{\mu} + 30$ kg/ha). To do so would first require an estimation of the social costs of overgrazing. Second, such an extension implies that the biologically defined upper bound does balance all public and private costs and benefits.

[8] Sampling for grass production over samples forb, browse, and aggregate production. Ideally, these latter three should be sampled using subsets of grass plots and costs reduced accordingly. Data on the costs of surveying each forage class are not available. Aggregate plot costs are applied to the number of plots to get cost curves which somewhat overestimate theoretically perfect survey costs.

TABLE 1. Total Sample Sizes Required to Estimate Grass, Forb, Browse, and Aggregate Forage Production Using Pooled Time-series and Cross-sectional Data for a Ten Year Period.[a]

Forage Production Categories	Sample Accuracy (kg/ha)	Confidence Levels					
		70%	75%	80%	85%	90%	95%
Grasses		738	918	1,118	1,420	1,864	2,630
Forbs		74	92	112	142	187	263
Browse		145	180	219	279	366	516
All Forages		551	685	834	1,060	1,392	1,964
Sample Size Needed	$\hat{\mu} - 10$	740	920	1,120	1,420	1,870	2,630
Grasses		185	229	279	354	465	657
Forbs		19	23	28	36	47	67
Browse		37	45	55	70	93	131
All Forages		138	171	208	264	347	490
Sample Size Needed	$\hat{\mu} - 20$	190	230	280	360	470	660
Grasses		83	101	124	158	208	294
Forbs		9	11	13	17	22	31
Browse		17	20	25	32	42	60
All Forages		62	76	92	118	155	219
Sample Size Needed	$\hat{\mu} - 30$	90	110	130	160	210	300

[a] N = number of plots rounded up to the next whole number to eliminate fractions.

plant health. Range scientists have developed proper use factors (PUF) for each forage species. These are the percentages of annual production which can be harvested by grazing animals without abusing forage plants. PUF's from the Big Lost River-Mackey Area of BLM's Idaho Falls District Office were used to reduce total herbage grown to the amount available for grazing.[9] Since grass, forb, browse, and aggregate production was reported by species, the reduction adjustment was based on a weighted annual average applied to total production. The PUF used was 0.3169; i.e., 32 percent of annual production can be consumed. The adjusted long term use was 2,907 animal units.[10] This figure becomes 2,810, 2,843, and 2,875 animal units at $\hat{\mu}$-30, $\hat{\mu}$-20, and $\hat{\mu}$-10 kg/ha confidence intervals, respectively, when production is reduced to the lower range of each. To determine the value of grazing available from the 44,048 hectare study area, the 1980 BLM grazing fee of \$1.81/AUM was multiplied by twelve to give \$21.72, the value of a year's forage.[11] At the three confidence intervals listed above, the grazing available is worth \$61,033, \$61,749, and \$62,445 per year, respectively. Narrowing the confidence interval from −30 kg/ha to −10 kg/ha provides a revenue gain of \$1,412 per year.[12]

[9] Supplied by Allan W. Strobel, Range Conservationist, Denver Service Center, BLM, USDI.

[10] An animal unit equals the amount of forage necessary to support a cow with calf at side for 12 months. All calculations made were based on annual equivalents because comparisons are easier to make and no information is lost even though seasonal use considerations are masked.

[11] Valuing additional AUM's of grazing at the BLM grazing fee could be a conservative estimate. While it may be the correct value from the point of view of the public agency, because public grazing is a rationed commodity, additional grazing may be more valuable to users. That use value would be imputed based on the grazing's contribution to production and the price of the next best alternative source of forage (anonymous reviewer comment).

[12] All production, costs, and returns figures are annual values.

TABLE 2. Annual Total Variable Survey Costs for Average Production Estimates at Six Significance Levels for Each of Three Confidence Intervals.[a,b]

Significance Level	Confidence Interval (kg/ha)		
	$\hat{\mu} - 30$	$\hat{\mu} - 20$	$\hat{\mu} - 10$
70%	$ 57.60	$121.60	$ 473.60
75%	70.40	147.20	588.80
80%	83.20	179.20	716.80
85%	102.40	230.40	908.80
90%	134.40	300.80	1,196.80
95%	192.00	422.40	1,683.20

[a] Cost of $6.40 per plot based on BLM weight estimate method reported in Rangeland Inventory Analysis (Draft) 1981.
[b] Production and revenue figures are calculated on an annual basis to conform with cost figures.

Sampling strategies involve increasing significance levels as well as narrowing associated confidence intervals. The economic issue is balancing incremental changes. Increasing significance levels at given confidence intervals can be interpreted as an insurance strategy for the land management agencies. The additional costs associated with implementing this strategy are shown in Table 3 and Figure 1. The level of significance is important because it measures the stability of a production estimate. However, increasing significance levels does not increase the amount of saleable forage. It does make the selling agency more certain that the amount sold is correct.[13] Narrowing the confidence interval at a given significance level increases the amount of saleable forage. The costs of narrowing confidence intervals rise at increasing rates as accuracy improves. This can be explained by considering the area under the curve which represents the normal distribution. With a wider interval such as −50 kg/ha, the area excluded in the tail of the curve is fairly small. Therefore, samples are small. As the interval is narrowed, the space which is excluded expands at an increasingly greater rate because of the shape of the normal curve. Consequently, the sample size required rises at an increasing rate, causing a similar effect on costs.

[13] The value of an increased level of confidence depends on the costs of overgrazing. If the amount of grazing sold exceeds the amount which should have been sold and causes a degradation of the resource, the costs of reclamation must be considered.

TABLE 3. Annual Additional Costs of Improving Significance Levels of Average Production Estimates at Three Confidence Intervals.

Significance Level Increase	Confidence Interval (kg/ha)		
	$\hat{\mu} - 30$	$\hat{\mu} - 20$	$\hat{\mu} - 10$
70% to 75%	$12.80	$ 25.60	$115.20
75% to 80%	12.80	32.00	128.00
80% to 85%	19.20	51.20	192.00
85% to 90%	32.00	70.40	288.00
90% to 95%	57.60	121.60	486.40

Narrowing the confidence interval associated with estimated inventory levels increases the amount of forage available for sale during certain periods of the year, and therefore, revenue flows. Finally, the optimum combination of significance level and confidence interval identifies the economically optimum expenditure for survey improvement.

As noted earlier, at a given confidence interval, total and additional revenue remains constant for all significance levels. Since the issue is lost revenue, this revenue calculation is based on the lowest level of production in the interval. Revenue may be increased only by narrowing the confidence interval to identify saleable forage which would otherwise remain unrecognized.

Production Estimate Accuracy

Because agency personnel manage conservatively and discount for uncertainty, the number of animals stocked will be no greater than available information allows. These rates are not affected by changing the significance level. The choice of significance level is dictated by the accuracy with which managers feel comfortable.

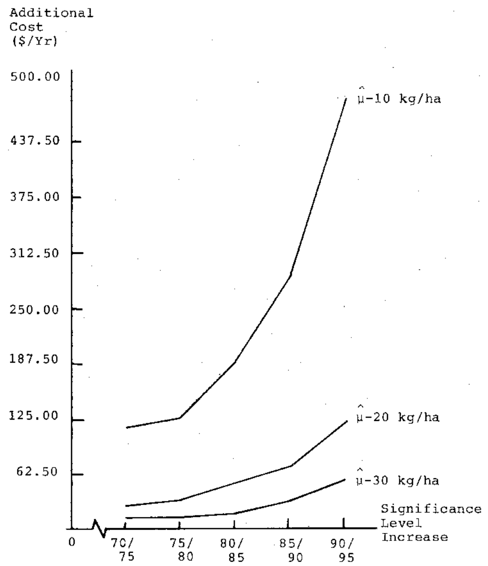

Figure 1. Additional Annual Cost of Increasing Significance Levels of Annual Forage Production Estimates at Each of Three Confidence Intervals.

The amount of grazing available can be increased only by tightening the confidence band about the mean estimated production. This analysis assumes conservative stocking rates and deals with reducing underestimates of the mean. Reducing forage production estimates from $\hat{\mu} - 30$ kg/ha to $\hat{\mu} - 20$ kg/ha or to $\hat{\mu} - 10$ kg/ha represents a 10 or 20 kg/ha improvement in estimated forage production. Adjusting estimated production by appropriate allowable use factors gives the actual amount of additional forage available for sale.

Confidence Interval Improvement

Beyond legalities, the important economic issue associated with underestimating forage production is the opportunity cost of wasted resources. Both agencies and ranchers are affected. Agencies lose revenue because available forage is not sold. Ranchers have to find alternative forage sources if they wish to expand herd or flock sizes above what the present forage base is estimated to carry. Producer income is reduced because either production is foregone or higher expenses are incurred.

TABLE 4. Annual Addition Cost of Improving Confidence Intervals for Annual Production Estimates at Six Significance Levels.

Significance Level	Confidence Interval Improvement (kg/ha): $\hat{\mu} - 30$ to $\hat{\mu} - 20$	$\hat{\mu} - 30$ to $\hat{\mu} - 10$
70%	$ 64.00	$ 416.00
75%	76.80	518.40
80%	96.00	633.60
85%	128.00	806.40
90%	166.40	1,062.40
95%	230.40	1,491.20

In this analysis, $\hat{\mu} - 30$ kg/ha was taken as the minimum allowable range survey confidence interval. Whether or not it would pay to tighten the confidence interval to −20 kg/ha or −10 kg/ha is determined. The cost of obtaining better estimates of forage available arises from the cost of improving survey accuracy by tightening confidence intervals, as shown in Table 4. The analysis is based on 1980 costs and revenues. Since both annual sample size and annual average productivity are assumed to be equal over time, the findings are based on first year costs and returns. Discounting over the ten year period was not performed because it would be a linear transformation and leave the results unchanged.

Increasing the sampling intensity to tighten the confidence interval from 30 kg/ha to 20 kg/ha is economically justified at all significance levels, as shown in the lower half of Figure 2. The net benefit was $652 at 70 percent significance, decreasing to $585.60 at the 95 percent level. Additional net revenue drops $66.40 if agency personnel want 95 percent significance rather than 70 percent. At the $\hat{\mu} -$ 20 kg/ha confidence interval and 95 percent significance level, the marginal cost

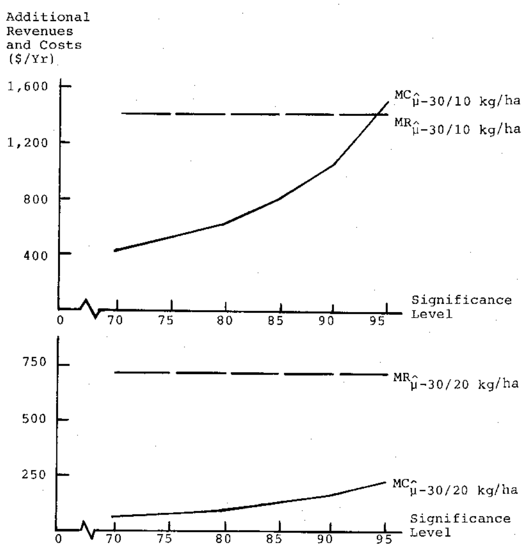

Figure 2. Optimum Significance Level at Which to Sample Based on Additional Revenues and Costs Associated with Improving the Confidence Intervals Around Annual Production Estimates from $\hat{\mu}$ − 30 to $\hat{\mu}$ − 20 to $\hat{\mu}$ − 10 kg/ha.

of adding additional survey plots is still below the revenue generated by tightening the confidence interval by 10 kg/ha and selling additional forage. It may be speculated that higher significance is economically feasible but that costs and returns converge rapidly.

An economic limit is reached when the confidence interval is tightened from −30 kg/ha to −10 kg/ha. The upper half of Figure 2 shows it is possible to increase the significance level from 70 percent to 90 percent while tightening the confidence interval from −30 to −10 kg/ha. Marginal revenue still exceeds marginal cost. Net benefits decrease from $996 at 70 percent to $349.60 at the 90 percent significance level. In this instance, a managing agency can use $646.40 of the additional net revenue per year to be 90 percent certain of the stocking rate. The marginal revenue from grazing fees and the marginal cost of increasing survey intensity intersect at a 94 percent significance level and −10 kg/ha confidence interval. It was noted earlier that additional grazing sale revenues always exceeded survey costs. For legal reasons it is probably worth increasing the significance level to 95 percent, which is the generally accepted scientific norm. The marginal cost of increasing survey intensity would exceed marginal revenue by $79.20 per year.

Maximized Annual Sample Strategy

No published research has been found giving an a priori statistical reason for choosing a specific distribution of survey plot numbers over the ten year time frame. Consequently, all statistically valid sampling schemes are equally likely to capture grazing production variation. However, since weather acts as a random variable in range production, a case can be made for taking an equal number of samples each year to best capture the impact of weather variability. The analysis in this section presents the extreme case in which information is so important that the entire sample must be drawn yearly. Annual sampling intensity will be ten times greater than before. The required sample size shown in Table 1 will be drawn annually. Consequently, marginal costs increase tenfold while marginal revenues remain unchanged.

The costs reported in Table 5 show that, at the 70 percent significance level, the marginal cost of tightening the confidence interval from $\hat{\mu}$ − 30 kg/ha to −20 kg/ha is $640. The marginal revenue generated by that increase is $716, which justifies the improvement. At the 75 percent significance level, the marginal cost of moving from −30 kg/ha to −20 kg/ha is $760.80. This exceeds marginal revenue by $52 per year. At the scientific norm of 95 percent significance, the marginal cost of tightening from −30 kg/ha to −20 kg/ha is $2,304. This is over three times the marginal revenue generated.

In all cases, the annual marginal cost of

TABLE 5. Additional Costs and Revenues Associated with a Maximum Information Strategy.

Significance Levels	Confidence Interval Improvement (kg/ha) $\hat{\mu}$ − 30 to $\hat{\mu}$ − 20 MR	MC	NR	$\hat{\mu}$ − 30 to $\hat{\mu}$ − 10 MR	MC	NR
70%	$716	$ 640	$ 76	$1,412	$ 4,160	($ 2,748)
75%	716	768	(52)	1,412	5,184	(3,772)
80%	716	960	(244)	1,412	6,336	(4,924)
85%	716	1,280	(564)	1,412	8,064	(6,652)
90%	716	1,664	(948)	1,412	10,624	(9,212)
95%	716	2,304	(1,588)	1,412	14,912	(13,500)

tightening the confidence interval from −30 kg/ha to −10 kg/ha is greater than the $1,412 annual marginal revenue. At a 70 percent significance level, marginal cost exceeds marginal revenue by $1,748. The deficit rises to $13,500 at the 95 percent significance level. It has been suggested that the 80 percent significance level should be the generally accepted accuracy for range management analyses (Mueggler). If this level is used, annual marginal costs of moving from −30 to −20 kg/ha or −10 kg/ha are $244 and $4,924, respectively. The revenue losses are shown in Table 5.[14]

Summary

Annual revenue increases usually exceed the increased annual variable costs of refining estimates for range forage production. These positive net benefits justify intensifying surveys from a 70 percent significance level and −30 kg/ha confidence interval to 95 percent (0.05) and −20 kg/ha. At this level of refinement marginal revenue exceeds marginal cost by $385.60 for the 44,048 hectare study area. Marginal revenue equals marginal cost at the 94 percent significance level and a confidence interval of −10 kg/ha. In both cases, the number of plots taken is distributed equally over the ten year management period specified by law.

At 80-percent significance, annual costs exceed revenues by $244 and $4,924 for confidence intervals tightened from −30 kg/ha to −20 or −10 kg/ha, respectively. In the most expensive cases, at the 95 percent significance level and a confidence interval of −10 kg/ha, annual variable cost increases exceeded revenue increases by $13,500. Total annual variable costs would be $16,832 to survey 44,048 hectares such as the study area. While not analyzed in detail, the $13,500 additional expense seems minor, about $4.70 per animal unit (12 months grazing).

The results of this study suggest that statistically valid surveys of range forage production can be economically justified in areas similar to the one in which this research was conducted. The additional information often more than pays for itself. In other cases, excess costs are minor. Reducing uncertainty and identifying grazing which is available, but unrecognized, are generally worthwhile.

[14] Results of analyses such as these will be sensitive to proper use factors, grazing fees, and survey costs. Since this study used discrete points in the analysis (i.e., confidence intervals of $\hat{\mu}$ − 10, $\hat{\mu}$ − 20, and $\hat{\mu}$ − 30 kg/ha), changes in the proper use factor or fee variables will vertically displace the revenue curves. Survey cost changes vertically displace the cost curves. For example, doubling the grazing fee doubles the seller's total and marginal revenues. The same phenomenon was demonstrated on the cost side. Increasing the sample size ten fold increased costs an equal amount. Consequently, care must be taken to ensure that regional variabilities are clearly understood. This is especially important because intersection of the revenue and cost curves determines the economically optimal information level. How these curves are positioned is dictated by variability in the factors discussed above, which in turn defines their point of intersection.

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